Statistical Typhoon Intensity Prediction Scheme

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NOAA/NESDIS

Introduction

- ONR funded the development of two statistical models to predict tropical cyclone intensity forecasting
  1. 5-day STIFOR for verification and comparison purposes
  2. Statistical Typhoon Intensity Prediction Scheme (Statistical-dynamical)

GOAL

- To quickly (1-year) develop a statistical-dynamical intensity forecast model for use in the western North Pacific

  1. Build on the success of this method in other basins

  2. Give JTWC two more intensity forecasting tools (STIPS/Decay STIPS, ST5D)
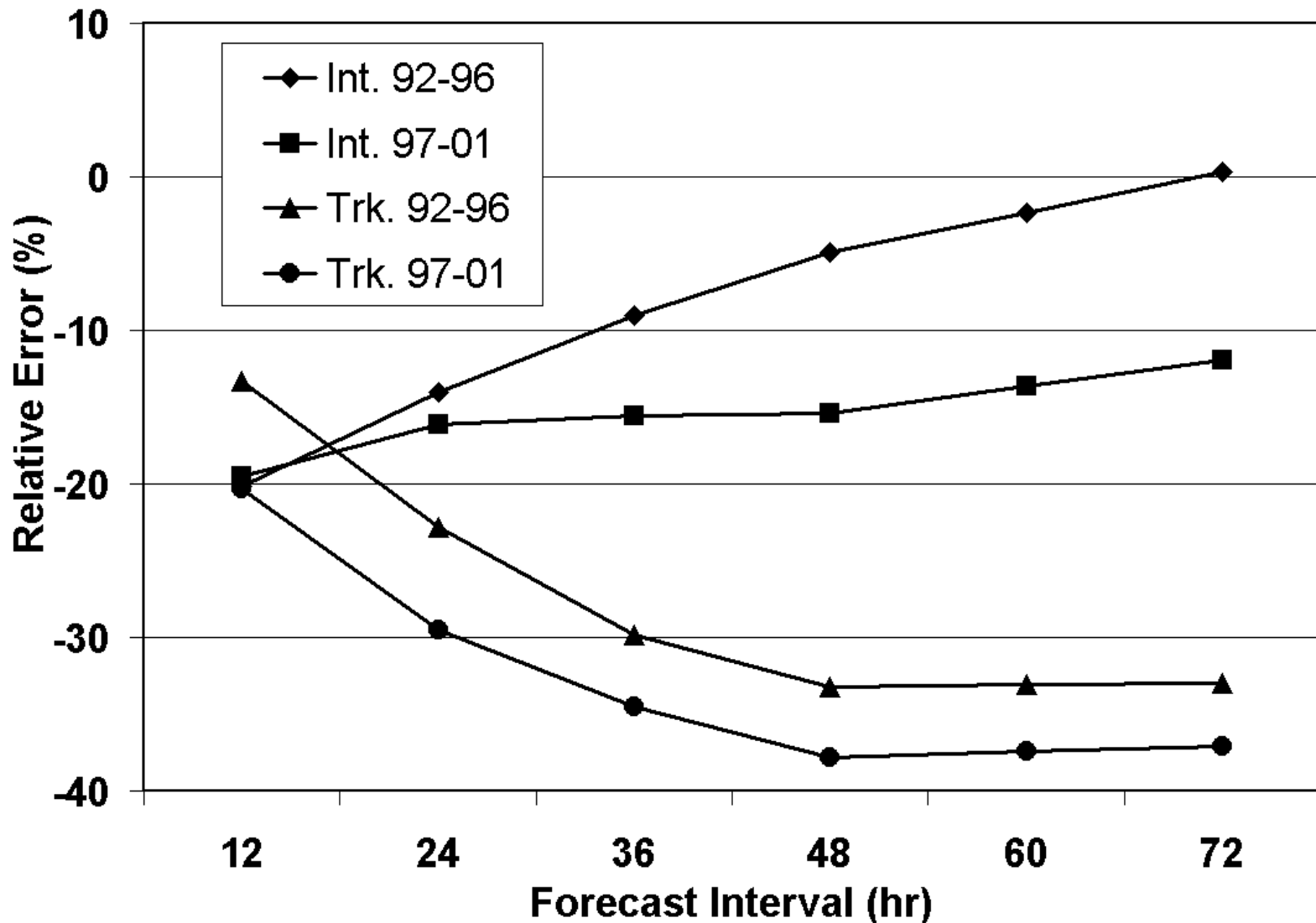
1997-2001 Normalized Intensity Errors*
Early models and official NHC
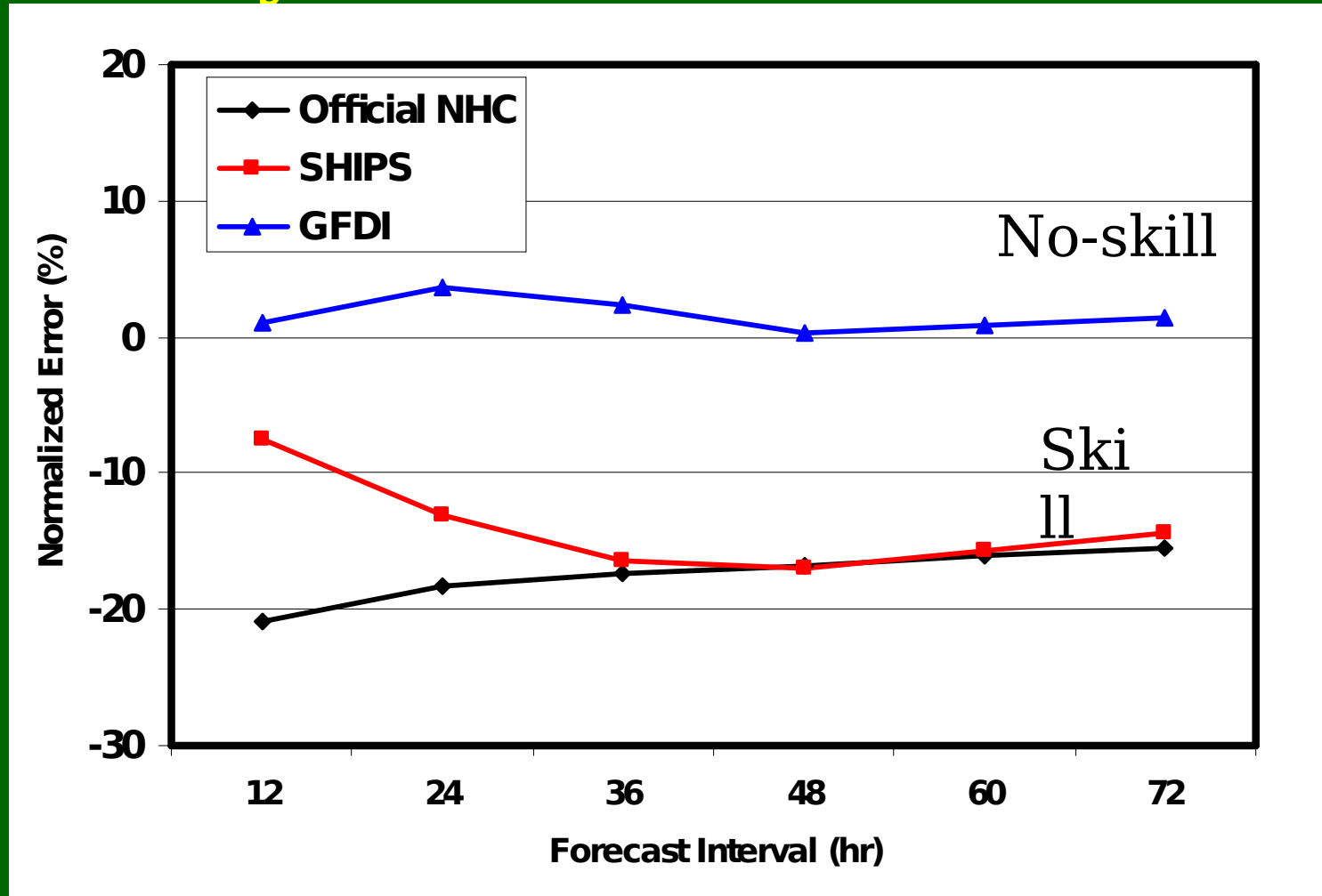
*Atlantic basin, NHC verification rules, 975 cases at 12h, 544 at 72 h,
 errors normalized by SHIFOR errors

NHC Official Track and Intensity Skill over the previous two 5-year periods

A New Climatology and Persistence model: ST5D vs STIFOR (CLIP)

- Use the change in intensity as the independent variable (predictand) – this is an easier quantity to predict than intensity

- Use quadratic terms in the statistical equations – allows better regression results.

- Makes forecasts through 5 days.

2001 Forecast Errors
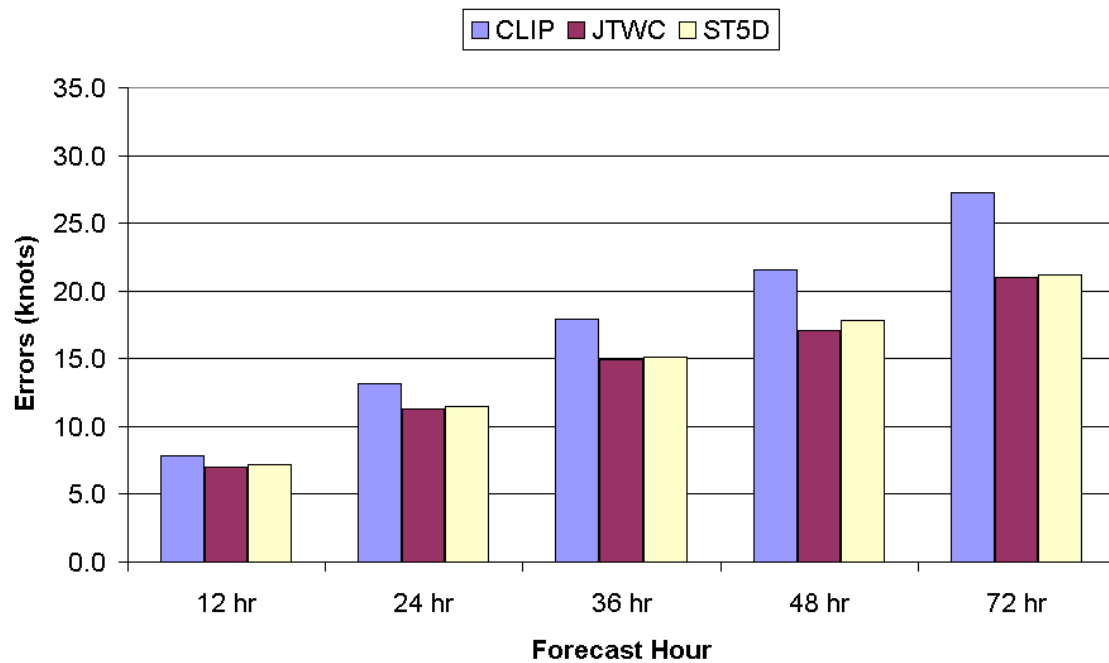
JTWC by a nose

2002 Forecast Errors
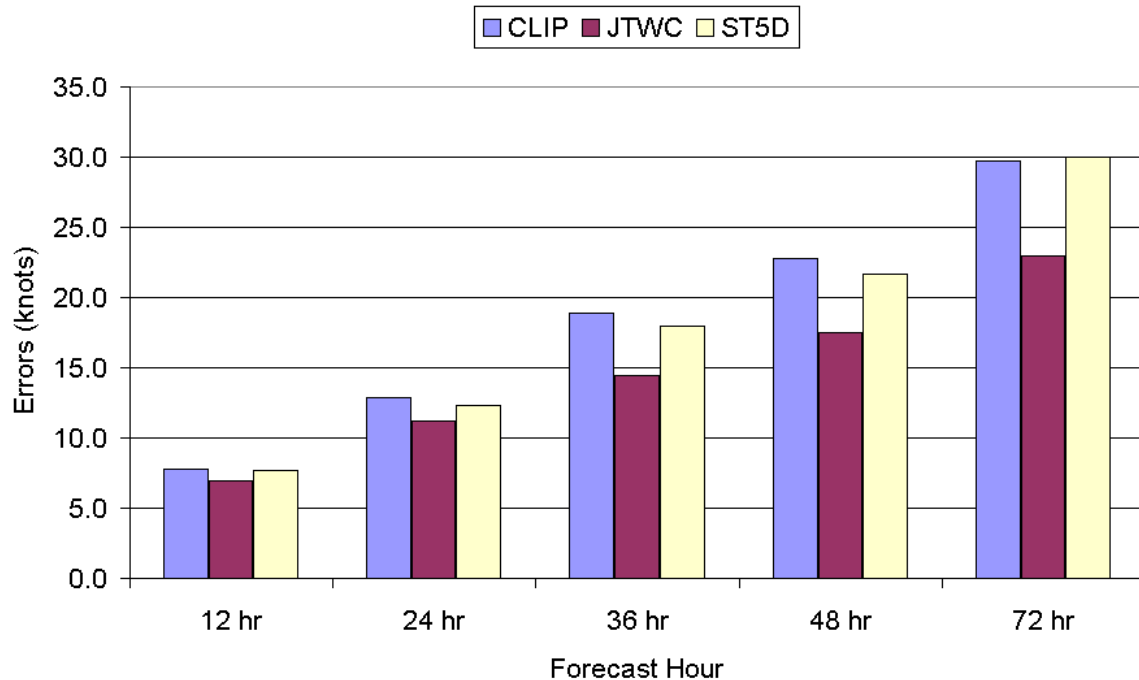
A February Supe[r] Typhoon?

Raising the "skill bar"... and the next step?

Relative Intensity Errors

Legend: 2001 wrt ST5D · 2002 wrt ST5D · 2001 wrt CLIP · 2002 wrt CLIP

No-skill

Skill

Y-axis: Relative Errors (%) — 25.0, 0.0, -25.0, -50.0

X-axis: Forecast Hour — 12 hr, 24 hr, 36 hr, 48 hr, 72 hr
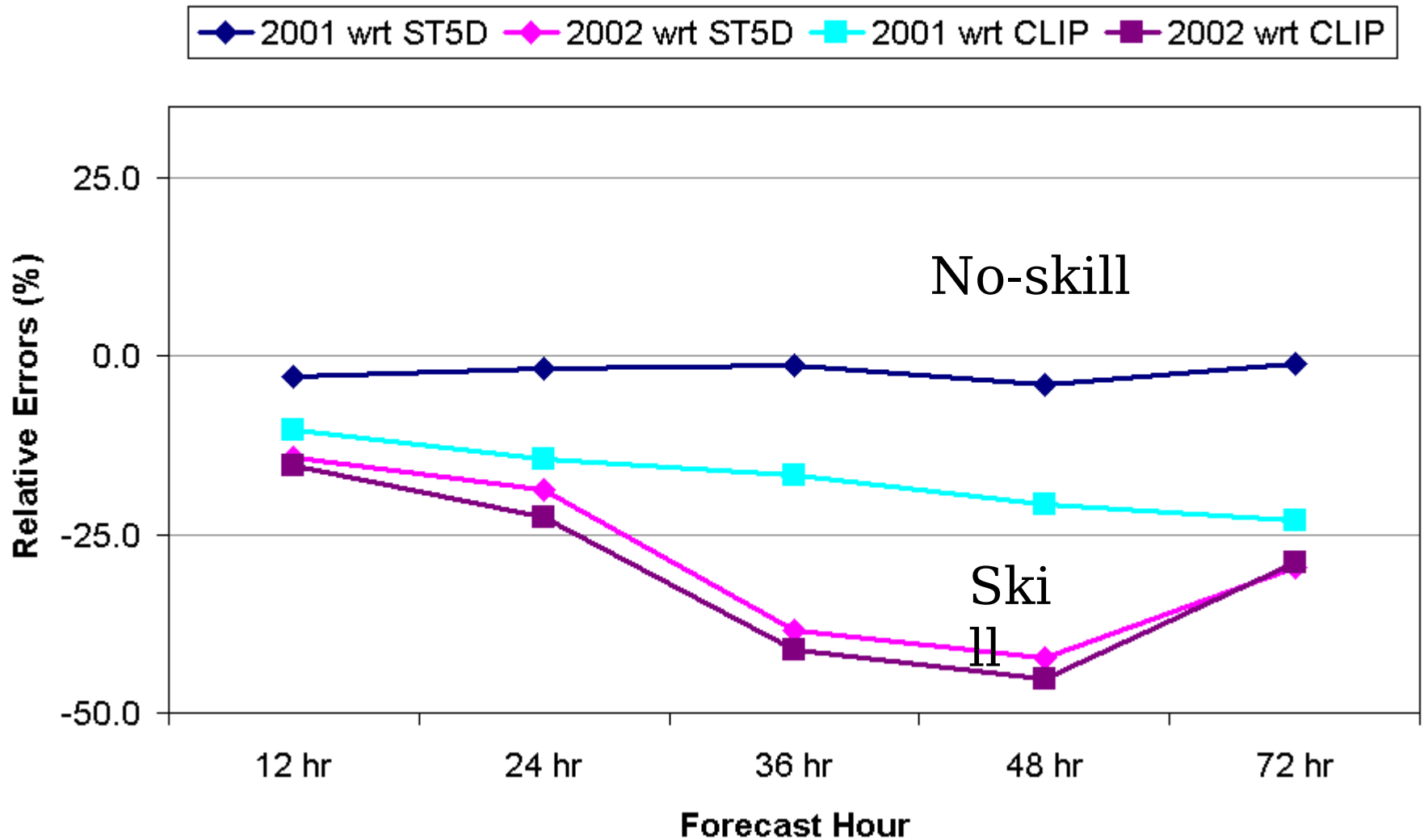
The Premise - STIPS should improve on ST5D because ...

- Takes advantage of synoptic information along a forecast track in addition to climatology and persistence
  - Shear
  - SST
  - Divergence
  - RH

STIPS Model Development

- The STIPS Model has a statistical-dynamical formulation in real-time applications, but was developed using a perfect prognostication assumption.
- In real-time forecasts
  1. analyses of fields are replaced by forecast fields
  2. The best track is replaced by the JTWC forecast
- Inland Decay is handled after the forecast is made
  1. South of 36 N the decay model follows Kaplan and DeMaria (1995)
  2. North of 40 N the decay model follows Kaplan and DeMaria (2001)
  3. Between 36N and 40N a linear weighting of these methods is applied

The Decay model is a function of
time over land, and forecast inter[...]

Faster decay at higher latitudes
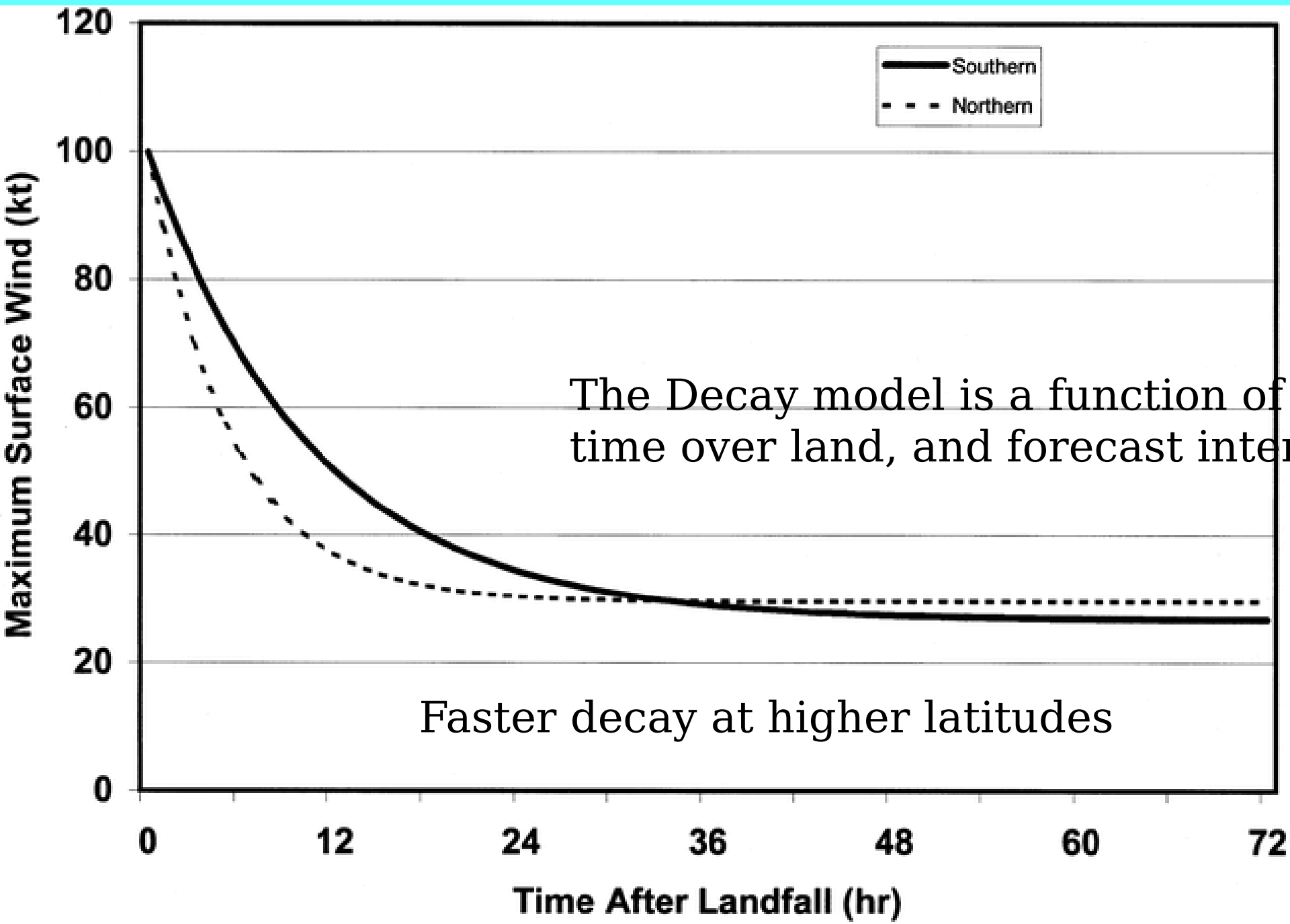
Datasets

- NOGAPS Analyses – Update Last week through 2001 WHY?
  - July 21,1997 – December 31, 2000 … now 2001
  - T, U, V, q, φ were collected twice daily at 100, 150, 200, 250, 300, 400, 500, 700, 850, 925, and 1000 mb
  - Skin temperature is used for SST
- Best track
  - same time period
- SST Climatology Levetus (1982) was used to fill in missing skin temperature
- Land and ocean was determined using a digitized dataset that contains continents and major Islands

Statistical Formulation

- Multiple linear regression.
- The change in intensity 12-h – 120-h is the independent variable
- 10 equations (12-h through 120-h)
- Two pools of potential predictors were tested
  1. 200 - 850 and 500 – 850 mb shear
  2. Generalized Shear 200 to 850 mb

Potential Predictors

- Climatology and Persistence Factors
- Synoptic Factors

CLIPER Predictors
from stifor5d

Predictor	Description
VMAX	Current Intensity
VMAX^2	Current Intensity square
DVMX	12-hour change in Intensity
JDAY	Absolute value of Julian Day minus 248
SPDX	Zonal Storm Motion

Potential Synoptic Predictors
(time averaged along the track)

Predictor	Description
MPI	Maximum Potential Intensity (MPI) - an empirical relationship
MPI^2	MPI squared
MPI*VMAX	MPI times the initial intensity
RHLO	Area averaged (200 km to 800 km) relative humidity 850 – 700 hPa
RHHI	Area averaged (200 km to 800 km) relative humidity 500 – 300 hPa
U200	Area average (200 km to 800 km) zonal wind at 200 hPa
T200	Area average (200 km to 800 km) temperature at 200 hPa
δ200	Area average (0 km to 1000 km) 200 hPa divergence
REFC	Relative Eddy Flux Convergence within 600 km (see Eq. 2)
GSHR	Generalized 200 to 850 hPa vertical wind shear (see Eq. 3)
SHRS	Area average (200 km to 800 km) 500 hPa to 850 hPa wind shear
SHRD	Area average (200 km to 800 km) 200 hPa to 850 hPa wind shear
SHRD*SIN(LAT)	200 hPa to 850 hPa wind shear times the sine of the latitude
GSHR*SIN(LAT)	Generalized wind shear times the sine of the latitude
ζ850	Area averaged (0 km to 1000 km) 850 hPa relative vorticity

Generalized Shear

$$\Delta V_{gen} = 4.0 * \sum_{P=850}^{p=200} w_p \sqrt{(u_p - \overline{u})^2 + (v_p - \overline{v})^2}$$, where

$$\overline{u} = \sum_{p=850}^{p=200} w_p u_p$$, the deep layer zonal wind,

$$\overline{v} = \sum_{p=850}^{p=200} w_p v_p$$, the deep layer meridional wind,

$$w_p$$ are mass weights.

The factor of 4.0 makes the values identical for a linear

Maximum Potential Intensity (MPI)

$$MPI = A + Be^{C(T-T_0)}$$

where A=38.21, B=170.72, C=0.1909 and T_0=30.0.

Maximum = 173 knots ~ 28.75 C
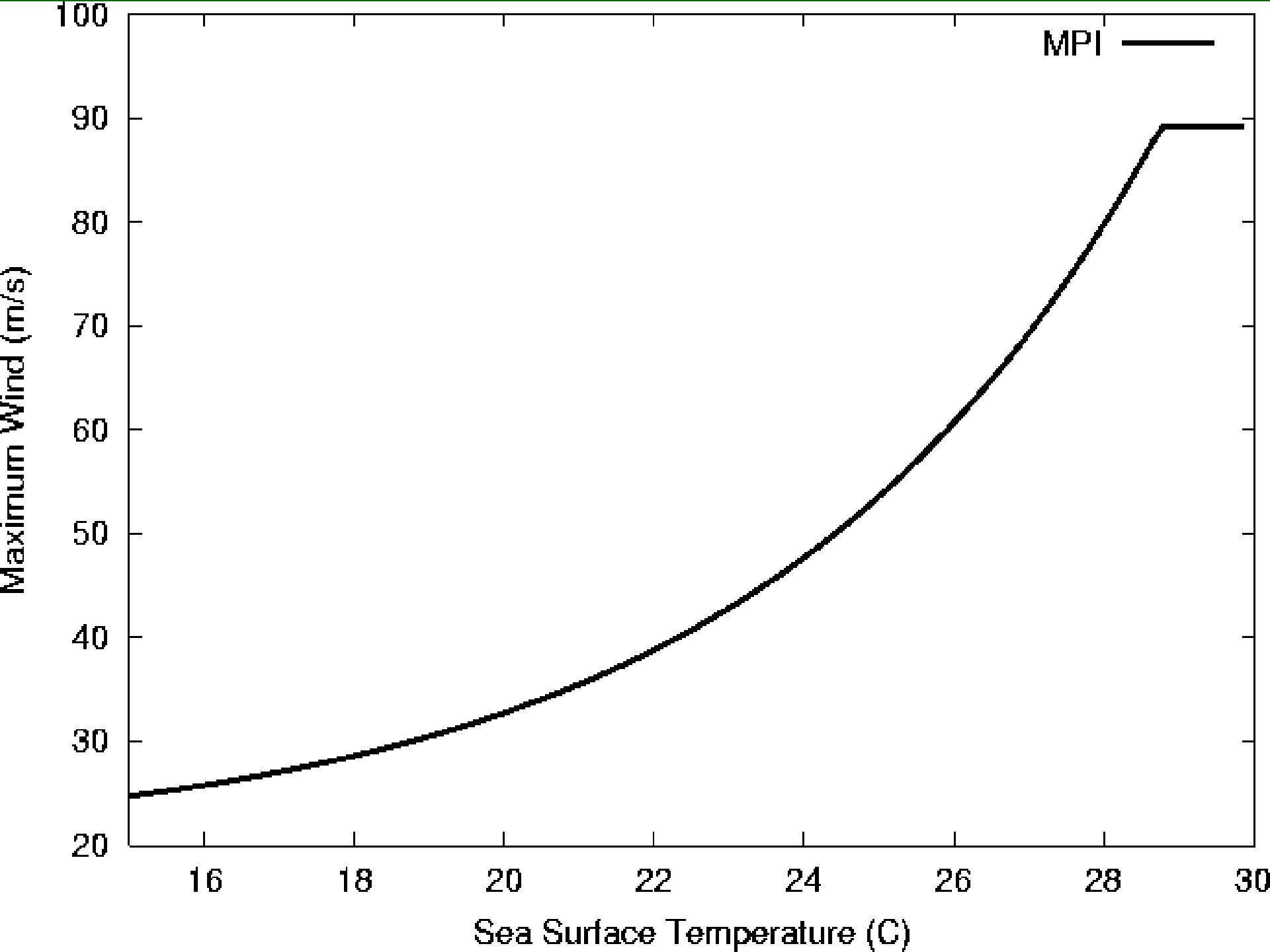
Relative Eddy Flux Convergence at 200 mb

$$REFC = -r^{-2} \frac{\partial}{\partial r} \left(r^2 \overline{U_L' V_L'} \right)$$

Where U (positive outward) is the radial wind, V (positive cyclonic) is the tangential wind, r is radius. Primes indicate deviations from an azimuthal mean, Over bars represent azimuthal means, and the subscript L denotes this calculation is done following the storm.

Statistical Methodology

- Two predictor pools (1.Layered and 2. Generalized shear)
- Independent variable intensity change from t=0.
- Stepwise predictor selection procedure is used to pick predictors at times 12-h through 120-h
- Once the selection is complete for all forecast times a combined predictor pool is created and the coefficients are then calculated using all predictors in the combined pool.

Final Combined Pool of 12 predictors

Predictor	Most Important Forecast Hour
1. DVMX (12-h change)	12
2. SPDX (zonal speed)	108
3. VMAX (intensity)	12
4. VMAX^2	12
5. MPI	24
6. MPI^2	24
7. MPI * VMAX	12
8. SHRG (generalized shear)	36
9. SHRG * sin (LAT)	108
10. U200 (200 mb U)	48
11. D200 (200 mb divergence)	24
12. RSHR (300-500 mb RH)	48

Input from the JTWC

- Through the ATCF
  - Storm Location at t=0, t=-12
  - Storm intensity and past intensity
  - Forecast Storm track 12 – 120hr

The predictors represent 8 Factors

- Sample Mean Changes
- Combined Intensity Change Potential
  - Combination of 5 predictors (VMAX, $VMAX^2$, MPI, MPI^2, MPI*VMAX)
- Vertical Shear
  - Combination of 2 predictors (SHRG, SHRG*LAT)
- U200 (in application combined with Vertical Shear)
- Persistence (DVMX)
- 200 mb Divergence
- 300 – 500 mb Relative Humidity
- Storm Motion

Sample Mean Intensity Change

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	4.	6.	9.	10.	13.	15.	17.	20.

Combined Intensity Changes Potential
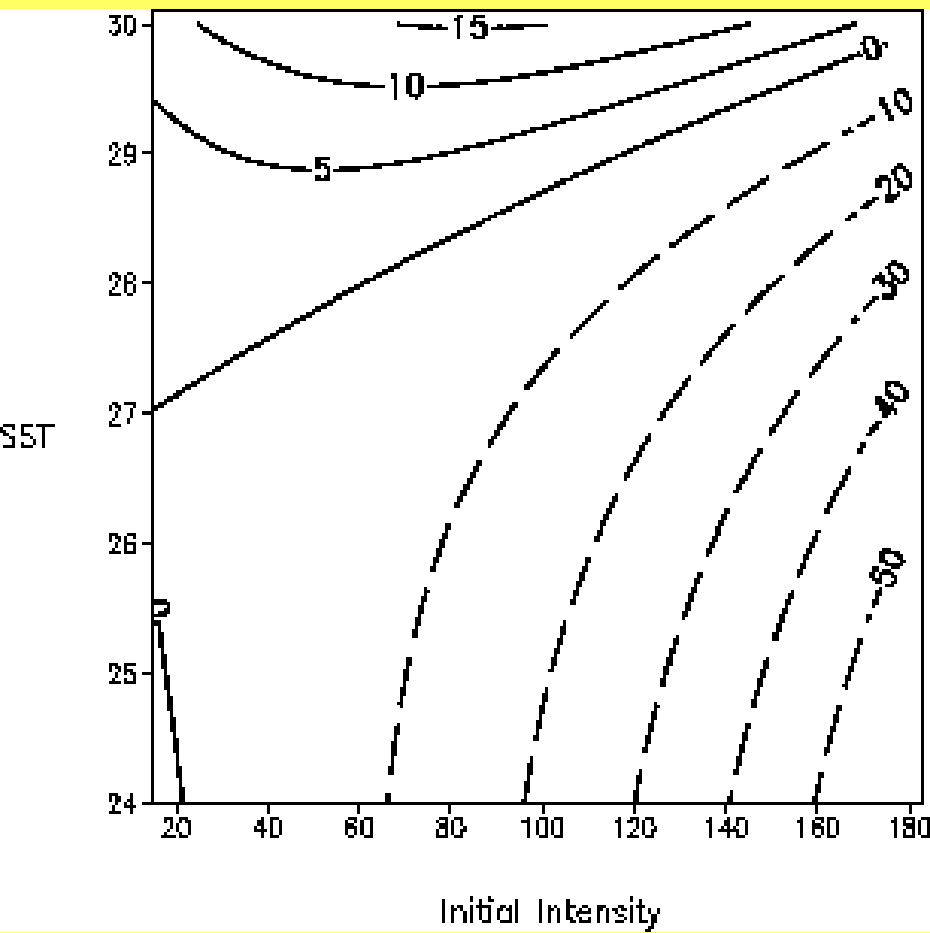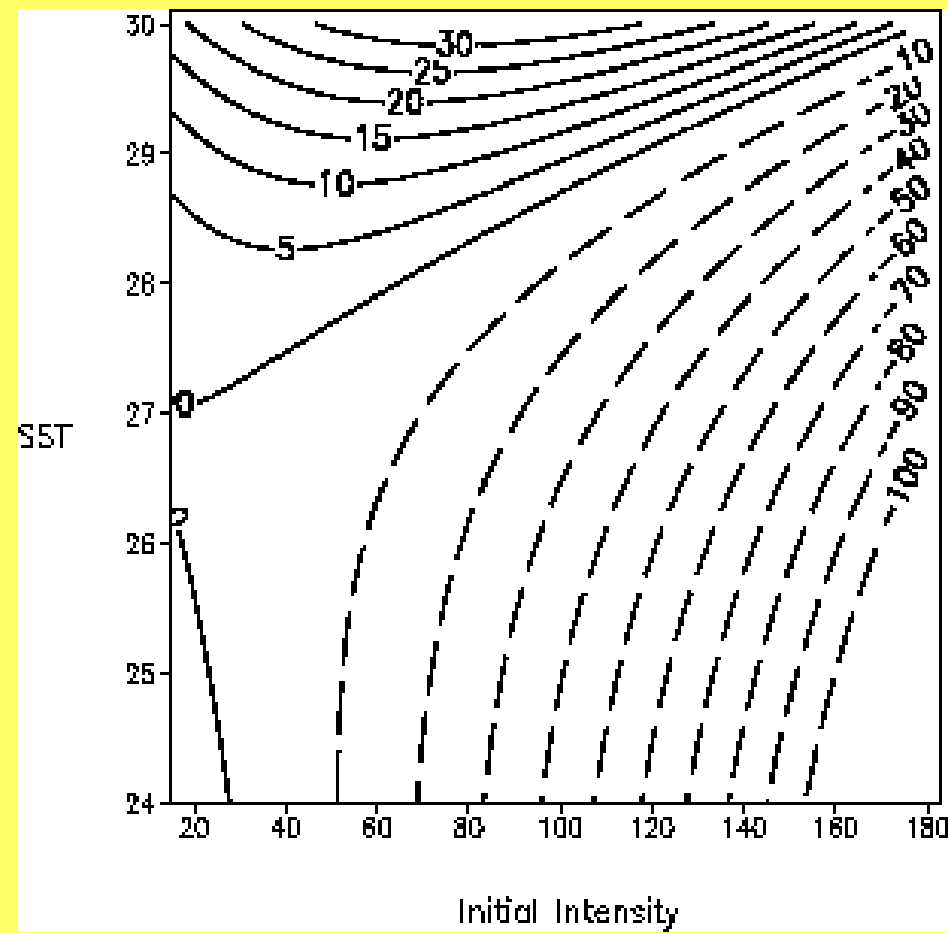
Potential + Mean Change (cont.)

36-h
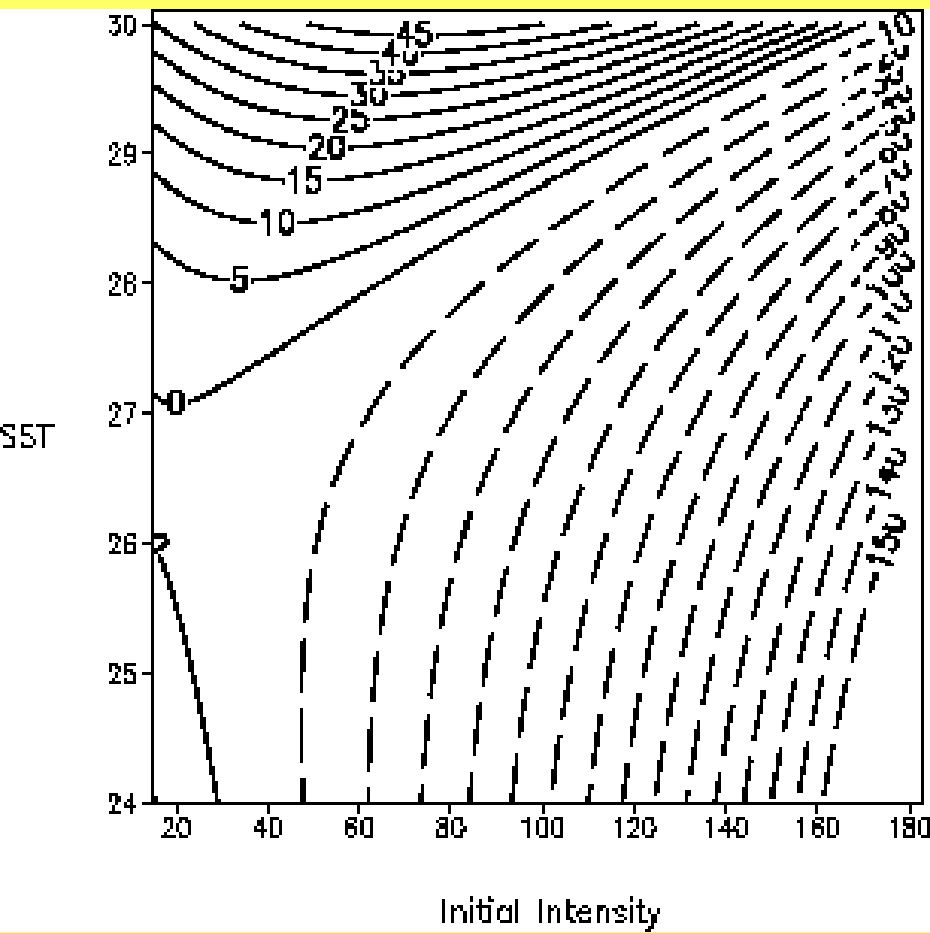
48-h
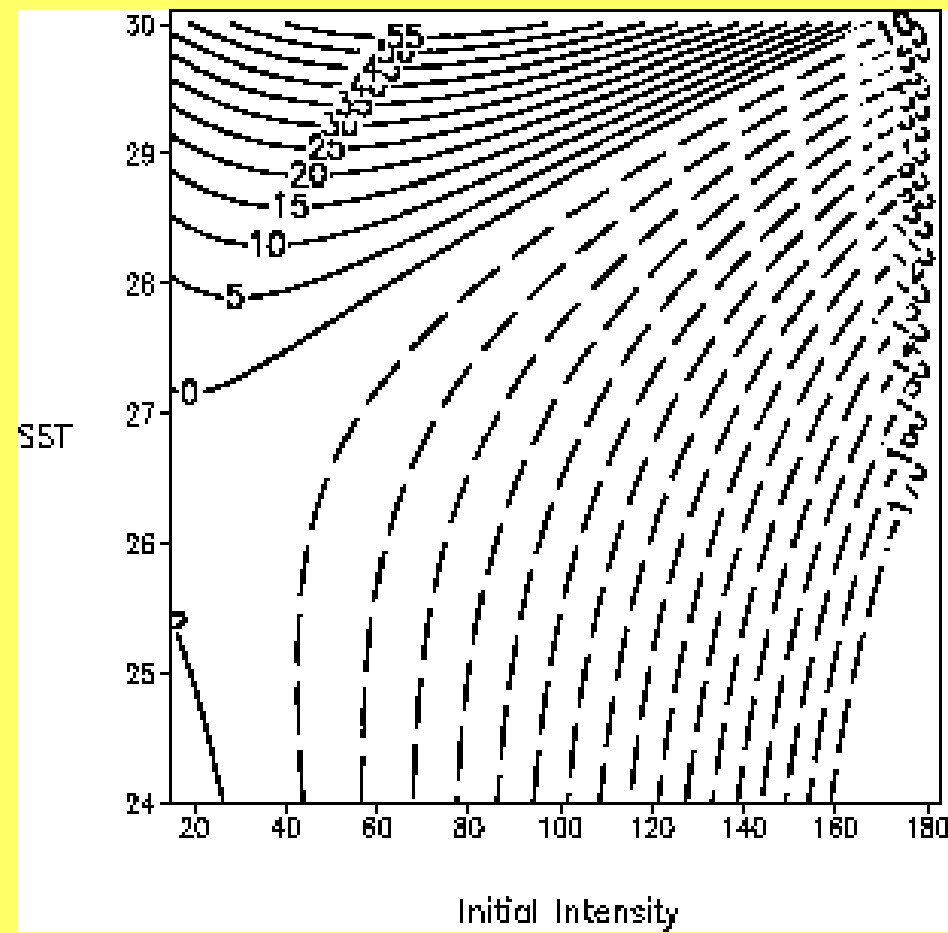
Vertical Shear
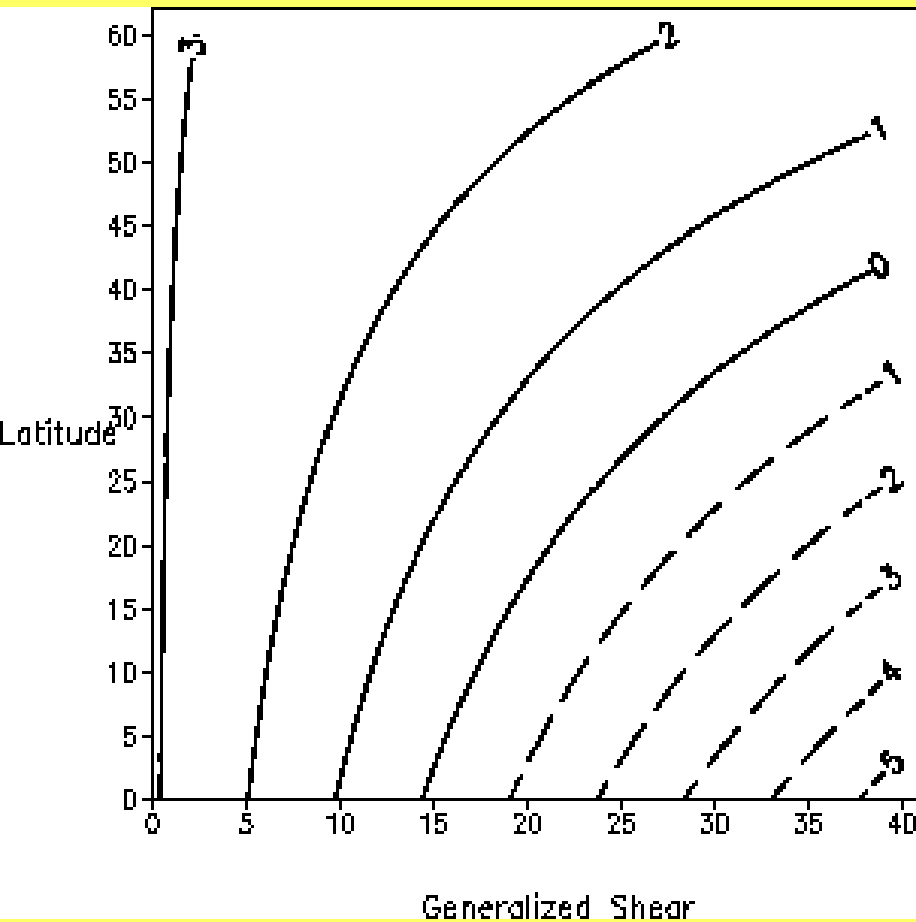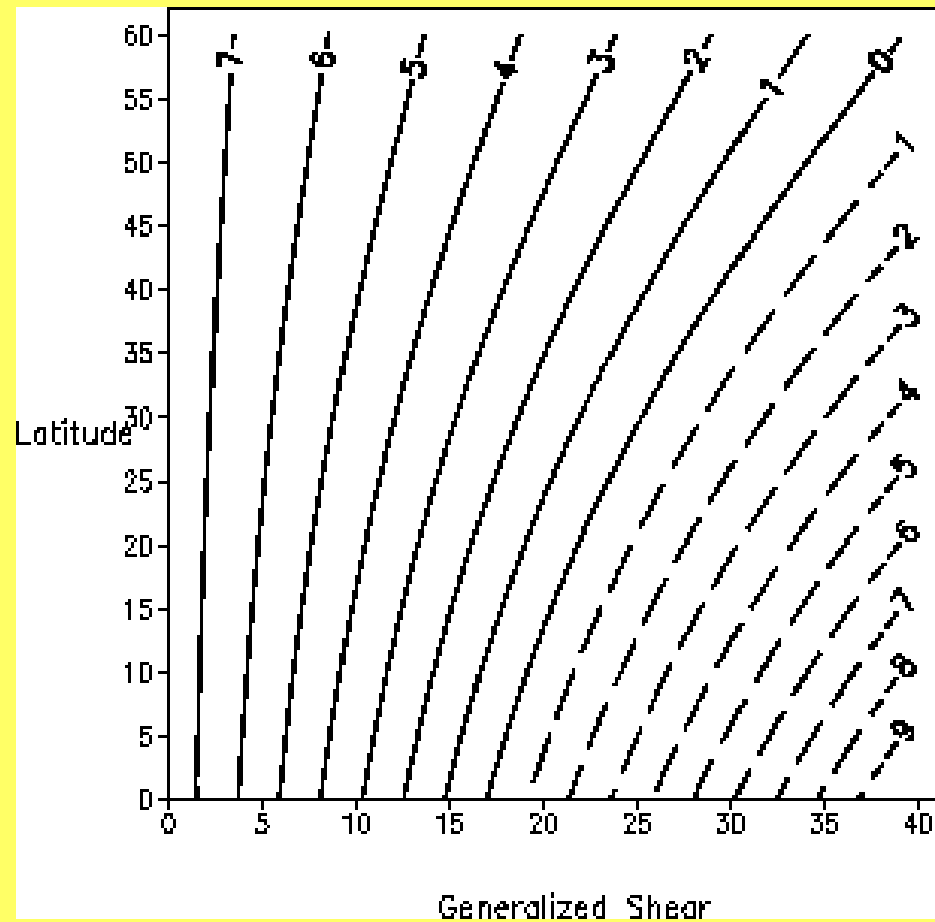
U200

- Recurvature factor.
  - Favors westerly 200 mb zonal winds
- However, strong positive zonal wind is almost always related to strong vertical wind shear in the developmental data, except at recurvature
- Weak zonal wind along with weak vertical wind shear often indicates a change in the steering flow associated with recurvature.
- Recurvature often is related to intensification (Riehl 1959)
- This term should be considered in combination with the vertical shear terms

Persistence – 12-h Intensity Change

- If intensifying, a storm will continue to intensify

- Most important at 12 hours

- Unimportant after 48 hours

Divergence

- Synoptic scale divergence is important at all times

- Requires about an average value of $6*10^{-6}s^{-1}$ in a 1000 km circle for intensification.

300-500 mb Relative Humidity

- important at all times beyond 12-h
- 58% and greater is favored for intensification.

Output

- STIP (STIPS)
- STID (Decay STIPS)
- One page STIPS summary output
- ATCF graphics

5-17-02
12 UTC
Example

Intensity Forecast – NONAME wp052002

Intensity Guidance

AID	12h	24h	36h	48h	72h	96h	120h
CONG	60	63	61	62	61	0	0
CONU	67	69	68	69	72	0	0
CON_	69	72	72	72	76	0	0
COSH	70	74	72	70	64	0	0
GFNI	81	84	83	80	77	0	0
ICON	66	69	70	71	72	0	0
JAVI	59	65	61	60	51	40	61
JGSI	61	62	62	64	72	0	0
JGSM	55	60	55	60	70	0	0
JTWC	65	75	75	70	65	70	65
JTWI	65	72	77	80	81	79	81
JTYI	64	70	70	72	79	0	0
JTYM	45	45	50	60	75	0	0
RECR	70	80	90	100	100	0	0
ST5D	67	72	73	75	74	73	64
STID	70	80	89	95	99	78	50
STIP	70	80	89	95	99	78	50

Time–Intensity Graph

Intensity Forecast

00h	12h	24h	36h	48h	72h	96h	120h
60	65	75	75	70	65	70	65

Gusts

00h	12h	24h	36h	48h	72h	96h	120h
75	80	90	90	85	80	85	80

Help   OK   Cancel

ATCF Graph Window – NONAME wp052002

File

Time Intensity for 05W

Intensity (kts)

Forecast Period

Legend:
- AFWI
- BABI
- CLIM
- CLIP
- CONG
- CONU
- CON_
- COSH
- COWI
- EGRI
- GFNI
- ICON
- JAVI
- JGSI
- JGSM
- JTWC
- JTWI
- JTYI
- JTYM
- NGPI
- RECR
- RJTI
- ST5D
- STID
- STIP
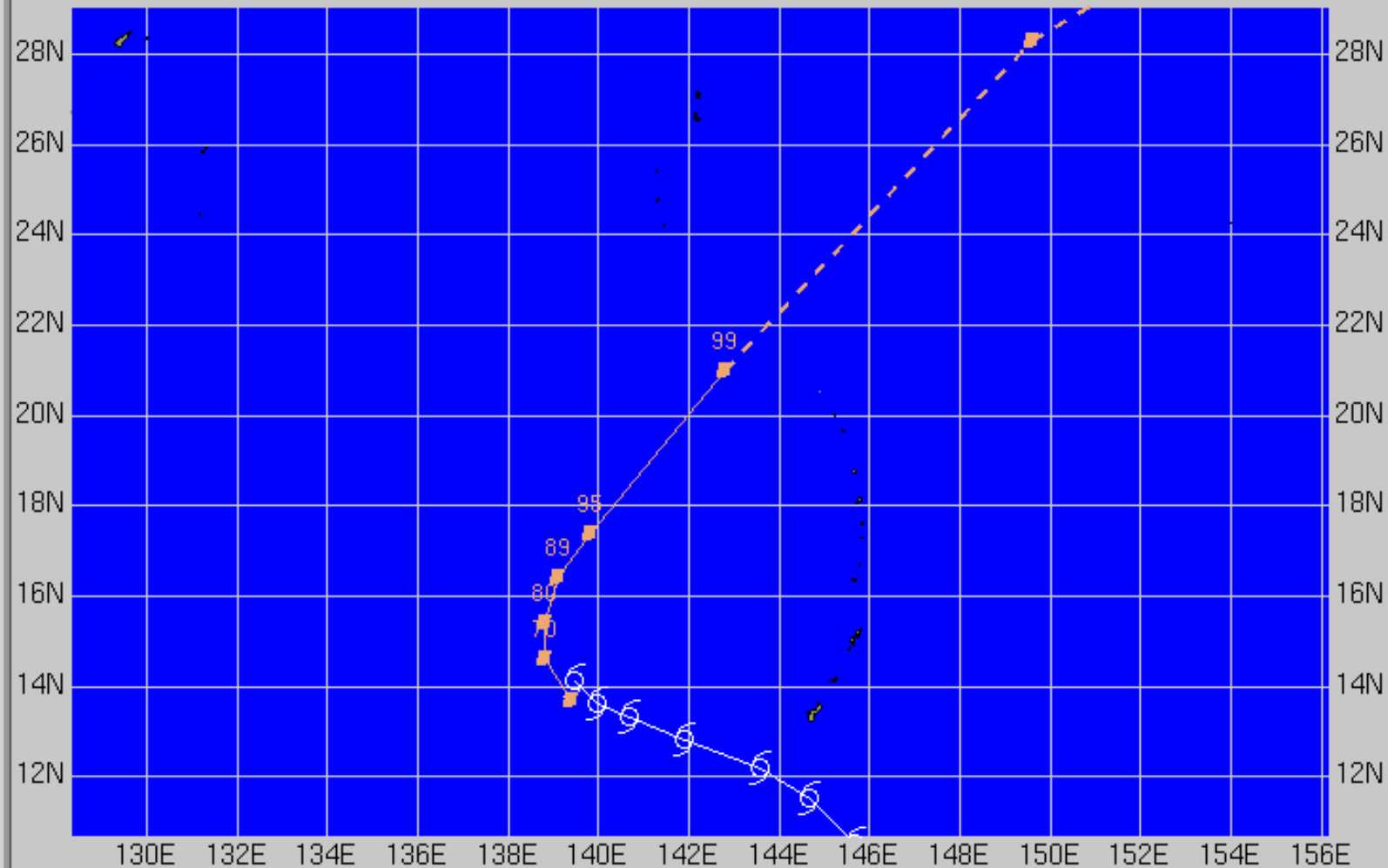
File

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                         WP0502
                    05-17-02  12 UTC


TIME (HR)          0    12    24    36    48    60    72    84    96   108   120
―――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――――
V (KT) NO LAND    60    70    80    89    95    99    99    93    78    64    50
V (KT) LAND       60    70    80    89    95    99    99    93    78    64    50



                 FACTORS RELATED TO THE STIPS FORECASTS
GEN SHEAR (KTS)          6     4     5     8    10    11    15    24    50    57    50
SST (C)         28.7  28.7  28.7  28.6  28.8  28.9  29.0  26.5  23.6  21.5  18.7
POT. INT. (KT)   172   172   172   169   173   173   173   126    89    72    58
200 MB U (KT)     -5     1     9    13    18    18    21    34    54    58    58
200 MB DIVG     72.0  54.0  44.0  61.0  24.0  52.0  29.0  78.0  61.0  48.0  34.0
500-300 MB RH     67    69    72    72    74    71    66    64    44    41    31
LAND (KM)       1533  1467  1485  1544  1649  1681  1552  1308  1166  1365  1554
LAT (DEG N)     14.1  14.6  15.4  16.4  17.4  19.2  21.0  24.6  28.3  31.2  34.1
LONG(DEG E)    139.5 138.8 138.8 139.1 139.8 141.3 142.8 146.2 149.6 154.4 159.2



         STORM SPEED/HEADING (KTS/DEG)        4/306
         EAST/NORTH STORM MOTION COMPONENTS  -3/  3
         PRESSURE OF STEERING LEVEL (MB)       550
         T-12 MAXIMUM WIND (KTS)                50




            INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

                    12    24    36    48    60    72    84    96   108   120
                  ------------------------------------------------------------
SAMPLE MEAN CHANGE  1.    2.    5.    7.    9.   11.   13.   16.   18.   20.
SST POTENTIAL       4.    9.   12.   14.   15.   15.    7.   -5.  -16.  -26.
VERTICAL SHEAR      1.    4.    7.   10.   12.   13.   13.   10.    7.    5.
PERSISTENCE         3.    3.    3.    2.    1.    0.    0.    0.   -1.   -2.
200 MB DIVG.        0.    0.    1.    0.   -1.   -2.   -1.   -1.   -2.   -4.
500-300 MB RH       0.    1.    2.    3.    4.    4.    3.    2.    2.    1.
ZONAL STORM MOTION  0.    0.    0.   -1.   -2.   -2.   -3.   -3.   -3.   -3.
                  ------------------------------------------------------------
TOTAL CHANGE       10.   20.   29.   35.   39.   39.   33.   18.    4.  -10.
                  ------------------------------------------------------------
```

Intensity Forecast – NONAME wp052002

Intensity Guidance

AID	12h	24h	36h	48h	72h	96h	120h
AFWI	84	75	66	56	0	0	0
BABI	86	75	62	49	0	0	0
CHIP	73	68	62	59	0	0	0
CLIM	88	80	90	87	90	0	0
CLIP	73	55	40	22	0	0	0
CONU	80	67	61	58	0	0	0
CON_	79	61	49	49	0	0	0
COSH	82	69	65	67	0	0	0
GFNI	88	67	53	53	0	0	0
JAVI	76	71	77	81	67	0	0
JTWC	75	60	45	30	0	0	0
JTWI	72	52	37	28	0	0	0
JTYI	70	56	46	45	0	0	0
ST5D	72	54	43	30	13	12	30
STID	70	52	48	52	0	0	0
STIP	70	52	48	52	0	0	0
XTRP	65	35	5	0	0	0	0

Time–Intensity Graph

Intensity Forecast

00h	12h	24h	36h	48h	72h	96h	120h
95	75	60	45	30	0	0	0

Gusts

00h	12h	24h	36h	48h	72h	96h	120h
115	90	75	55	40	0	0	0

Help   OK   Cancel

5-20-02 12 UTC Example

ATCF Graph Window – NONAME wp052002

File

Time Intensity for 05W

Intensity (kts)

CLIM

COSH
JAVI
GFNI
CONU
STID
JTYI
BABI
AFWI

JTWC
CLIP

ST5D

XTRP

Forecast Period

Legend:
- AFWI
- BABI
- CLIM
- CLIP
- CONG
- CONU
- CON_
- COSH
- COWI
- EGRI
- GFNI
- JAVI
- JGSI
- JTWC
- JTWI
- JTYI
- NGPI
- RJTI
- ST5D
- STID
- STIP
- XTRP
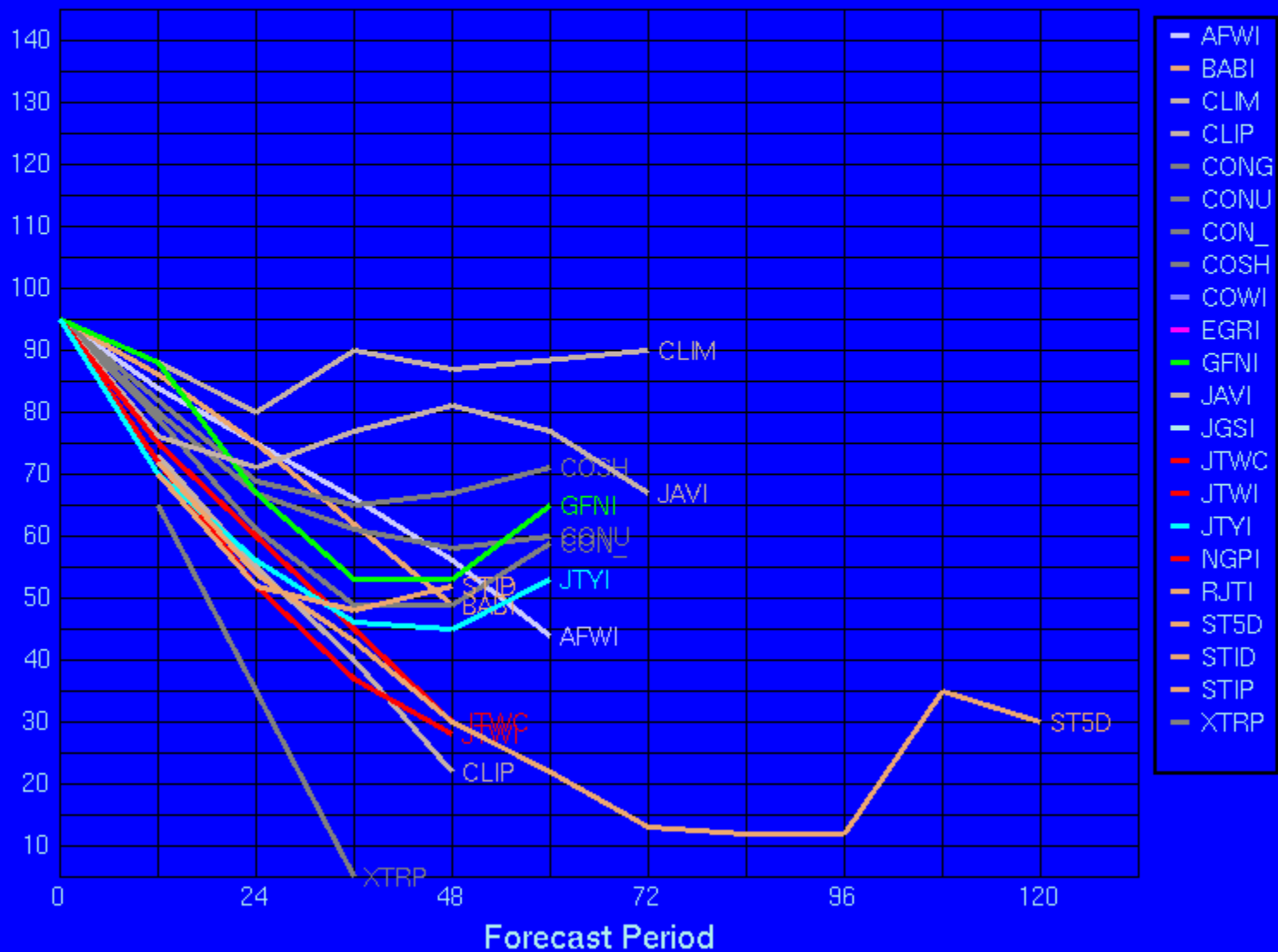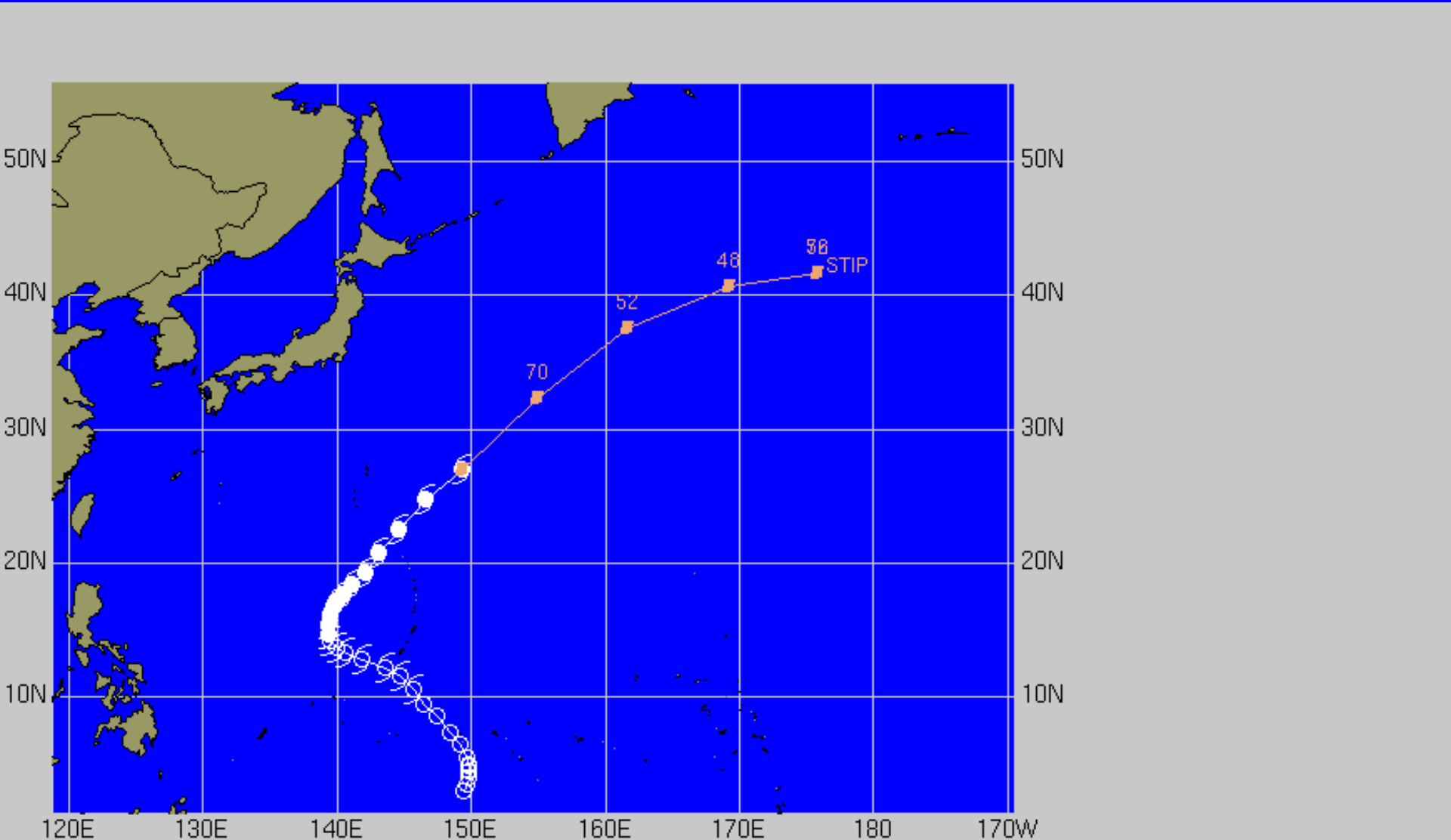
File

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                              WP0502
                         05-20-02  12 UTC
```

TIME (HR)	0	12	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	95	70	52	48	52	N/A	N/A	N/A	N/A	N/A	N/A
V (KT) LAND	95	70	52	48	52	N/A	N/A	N/A	N/A	N/A	N/A

FACTORS RELATED TO THE STIPS FORECASTS

	0	12	24	36	48	60	72	84	96	108	120
GEN SHEAR(KTS)	33	42	51	51	71	N/A	N/A	N/A	N/A	N/A	N/A
SST (C)	24.5	20.7	15.3	12.4	10.7	N/A	N/A	N/A	N/A	N/A	N/A
POT. INT. (KT)	98	67	49	44	43	N/A	N/A	N/A	N/A	N/A	N/A
200 MB U (KT)	39	47	60	80	93	N/A	N/A	N/A	N/A	N/A	N/A
200 MB DIVG	152.0	177.0	118.0	45.0	40.0	N/A	N/A	N/A	N/A	N/A	N/A
500-300 MB RH	64	65	71	64	54	N/A	N/A	N/A	N/A	N/A	N/A
LAND (KM)	1250	1370	1496	1508	1751	N/A	N/A	N/A	N/A	N/A	N/A
LAT (DEG N)	27.0	32.3	37.5	40.6	41.6	N/A	N/A	N/A	N/A	N/A	N/A
LONG(DEG E)	149.3	155.0	161.7	169.2	175.8	N/A	N/A	N/A	N/A	N/A	N/A

```
     STORM SPEED/HEADING (KTS/DEG)      36/ 43
     EAST/NORTH STORM MOTION COMPONENTS 28/ 26
     PRESSURE OF STEERING LEVEL (MB)    651
     T-12 MAXIMUM WIND (KTS)            125
```

INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	5.	7.	9.	11.	13.	16.	18.	20.
SST POTENTIAL	-21.	-43.	-55.	-62.	-64.	-65.	-65.	-59.	-54.	-49.
VERTICAL SHEAR	2.	3.	6.	9.	11.	13.	15.	13.	9.	5.
PERSISTENCE	-11.	-14.	-14.	-10.	-6.	-1.	3.	3.	7.	9.
200 MB DIVG.	4.	7.	9.	9.	12.	14.	16.	18.	19.	19.
500-300 MB RH	0.	1.	1.	1.	1.	2.	2.	1.	1.	2.
ZONAL STORM MOTION	0.	0.	1.	3.	6.	7.	8.	8.	9.	10.
TOTAL CHANGE	-25.	-43.	-47.	-43.	-32.	-19.	-8.	0.	8.	15.

Unfortunately I have no example of a storm that crosses land and decays

Expectations

- Expect to improve upon ST5D by about 10% through 84 hours based upon experience in other basins.

- Graphical and Text output will help the forecaster anticipate changes along the forecast track based upon their own experience.

Projected STIPS
Performance

Projected STIPS Performance (Average East Pacific and Atlantic)
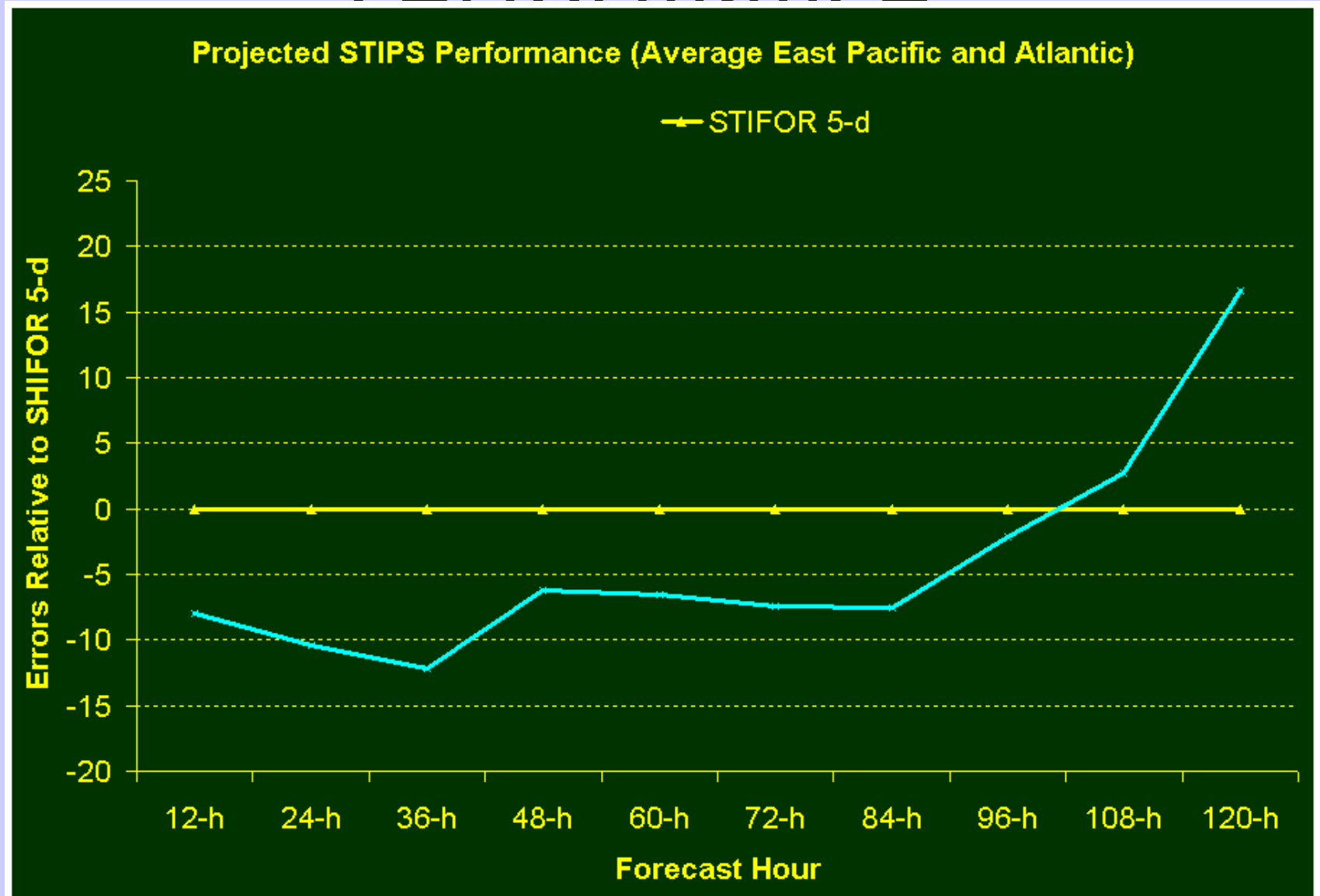
Includes depression s

Shortcomings

- Inaccurate input will adversely affect the forecasts (behind in intensity or large erroneous jumps in intensity, bad track forecasts, timing on landfall)
- Rapid intensification (i.e.42 mb/d) will not be predicted. Statistical models predict the mean changes and will underestimate rapid fluctuations in intensity.
- STIPS is dependent upon the forecast fields from NOGAPS.
- The inland decay model may cause rapidly weakening storms to decay slower over land (in STID than in the STIPS

Questions?

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    **********************************************************************
    * CIRA/NESDIS STATISTICAL TYPHOON INTENSITY PREDICTION SYSTEM (STIPS) *
    *                 WEST PACIFIC 5-DAY FORECASTS                        *
    **********************************************************************



                      TESTSTORM    12/18/01  12 UTC


TIME (HR)        0     12    24    36    48    60    72    84    96   108   120
_____

V (KT) NO LAND   55    59    64    68    69    69    66    63    59    52    55
V (KT) LAND      55    59    64    68    69    69    66    63    59    52    55



                  FACTORS RELATED TO THE STIPS FORECASTS
GEN SHEAR (KTS)  10    11    13    15    19    17    17    14    12   N/A    10
SST (C)         29.6  29.2  28.9  28.7  28.7  28.8  28.6  28.3  28.2  26.2  28.3
POT. INT. (KT)  173   173   173   172   172   173   169   162   160   121   162
200 MB U (KT)    -4    -8    -9    -8    -5    -6    -8   -10   -12   N/A   -10
200 MB DIVG     52.0  17.0   1.0  19.0  20.0  44.0  33.0  38.0  44.0   N/A  70.0
500-300 MB RH    62    58    65    72    74    71    68    71    72   N/A    78
LAND (KM)       2043  1958  1902  1869  1850  1841  1837  1805  1784  1810  1861
LAT (DEG N)      5.7   5.9   6.1   6.8   7.5   8.3   9.1   9.9  10.7  11.9  13.1
LONG(DEG E)    162.0 160.8 159.9 158.7 157.5 156.1 154.7 152.9 151.2 149.1 147.1
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STORM SPEED/HEADING (KTS/DEG)        6/280
EAST/NORTH STORM MOTION COMPONENTS  -6/  1
PRESSURE OF STEERING LEVEL (MB)      633
T-12 MAXIMUM WIND (KTS)               55
```

INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	4.	6.	9.	10.	13.	15.	17.	20.
SST POTENTIAL	4.	10.	14.	17.	18.	18.	16.	13.	6.	5.
VERTICAL SHEAR	0.	0.	-1.	-3.	-6.	-9.	-11.	-12.	-13.	-12.
PERSISTENCE	-1.	-1.	-1.	-1.	0.	0.	1.	1.	1.	2.
200 MB DIVG.	-1.	-2.	-4.	-6.	-7.	-9.	-10.	-11.	-12.	-12.
500-300 MB RH	0.	1.	1.	2.	3.	3.	3.	3.	4.	4.
ZONAL STORM MOTION	0.	0.	0.	-1.	-3.	-4.	-5.	-5.	-6.	-7.
TOTAL CHANGE	4.	9.	13.	14.	14.	11.	8.	4.	-3.	0.